Electromagnetic Propagation

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LONG TERM GOALS

Develop electromagnetic propagation models for use in operational or engineering propagation assessment systems.

OBJECTIVES

Develop an advanced unified hybrid radio propagation model based on parabolic equation and ray-optics methods for both surface-based and airborne applications. This model is named the Advanced Propagation Model (APM) and is the model used in the Advanced Refractive Effects Prediction System (AREPS). Resolve differences between current techniques used to model propagation effects under rough surface and strong ducting conditions.

APPROACH

We develop parabolic equation, ray optics, waveguide, and other models as necessary to produce both accurate and efficient models to be used in propagation assessment systems. In many cases we can use variations of existing models to achieve this goal, but sometimes completely new models are necessary. Once developed, these models are compared to other models and to experimentally collected propagation data for verification of accuracy. We stay abreast of other researchers' newest models by reading current literature, participating in propagation workshops, and attending conferences as appropriate. There is a strong international exchange of ideas and techniques in this area, as some important work is performed outside of the USA. This project is divided into two tasks: (1) Propagation Modeling, PI Amalia Barrios, and (2) Rough Surface Effects, PI Kenneth Anderson. For FY '03 we are planning on breaking this task into two separately funded tasks, Propagation Modeling (Barrios) and Rough Surface Effects on Microwave Propagation over the Sea (Anderson).

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14. ABSTRACT
Develop an advanced unified hybrid radio propagation model based on parabolic equation and ray-optics methods for both surface-based and airborne applications. This model is named the Advanced Propagation Model (APM) and is the model used in the Advanced Refractive Effects Prediction System (AREPS). Resolve differences between current techniques used to model propagation effects under rough surface and strong ducting conditions

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This project has developed a hybrid ray optics/parabolic equation propagation model for assessing the effects of the atmosphere and the environment in general on electromagnetic emissions in the range of approximately 100 MHz to 20 GHz for both surface based and airborne transmitters. We intend to expand the frequency range of applicability to 2 MHz to 20 GHz. Environmental effects include varying terrain elevation, range-varying refractive structure, and atmospheric absorption. One of the most significant deficiencies of this model is the lack of a validated (or even an agreed upon) method to account for wind-roughened sea surface effects at over-the-horizon ranges, especially under strong surface ducting conditions, in the parabolic equation model. This deficiency led to us to undertake an experimental and analytical program to develop a validated rough sea surface submodel for APM. The Rough Evaporation Duct (RED) experiment, completed last year in the Hawaiian Islands, was very successful and will lead to improved propagation models that will be incorporated into future versions of APM.

WORK COMPLETED

PROPAGATION MODELING

APM Ver. 1.3.1, along with the Computer Software Configuration Item (CSCI) documentation, has been submitted to OAML as part of the second round of QA resulting from last year's CIMREP evaluation. APM Ver. 1.3.1 incorporates many improvements and recommendations made by the CIMREP. One of the major improvements included in this newest version is a more efficient method in determining grazing angles necessary for rough surface and clutter calculations, which we developed. We have also begun research into developing a HF surface-wave model. The primary work during FY02 on this task consisted of gathering information regarding available HF models and establishing a general research model to use as a reference for the development of a HF surface-wave model to be included in a future update of APM.

ROUGH SURFACE EFFECTS

A mission plan was executed for the Rough Evaporation Duct (RED) experiment, 20 August to 18 September 2001. In February, we held a first-look data-analysis workshop at Scripps Institution of Oceanography, La Jolla, CA, where we had 17 presentations covering all of the major aspects of the RED experiment. In general, the RED experiment was very successful and data analysis is continuing. A special session on the RED experiment is planned for the upcoming 83rd Annual Meeting of the American Meteorological Society, which will be held 9-13 February 2003 in Long Beach, CA. This will be a joint session with the Shoreline Aerosol Environment Study (SEAS) and is sponsored by the 12th Conference on Interaction of the Sea and Air.

RESULTS

PROPAGATION OVER TERRAIN

A more efficient method for determining grazing angle required the use of ray tracing for the majority of applications. For over-sea cases the grazing angles are computed using a combination of ray trace and PE spectral estimation, with angles produced from ray trace given precedence. For over-land cases, the grazing angles are now computed using a combination of ray trace and angles produced by terrain slopes along the path, where again angles from ray trace are given precedence. Angles obtained from PE spectral estimation are also used as a supplement but are not given priority due to the angular limitations of the PE algorithm and its ability to properly account for higher reflection angles as would be encountered over terrain.

Our well-established waveguide model, MLAYER, is suitable down to roughly 30 MHz and provides an alternative method for comparing propagation calculations near an impedance boundary against PE results. However, we would like to extend the applicable frequency range of APM down to 2 MHz. To this end, a general model based on Norton's 'engineering solution' [1] of the propagation equations has been implemented. Along with MLAYER, this model will also be useful as an accuracy check tool in future development. We are also currently implementing Barrick's [2] rough ocean-surface impedance model to improve the accuracy of rough surface calculations at HF.

ROUGH SURFACE EFFECTS

During the RED experiment, we did not get the high winds and high evaporation duct heights that we had anticipated. There was only one Eastern Pacific tropical cyclone that developed but it had minimal impact on the sea-state in Hawaii. However, comparison of 5 minute averaged observed-to-modeled propagation data for all 6 sets of transmitters is very good. In the generation of the modeled data we used meteorological and surface inputs from the Naval Postgraduate School (NPS) buoy, which was located approximately 5 km westward (downwind) from *R/P FLIP,* and inputs derived from the University of California, Irvine (UCI) vertical array on *R/P FLIP*. Both of these data sets were used to drive the NPS "bulk model" that generated the refractive profiles needed by the Advanced Propagation Model (APM) to generate the modeled propagation data. The NPS bulk model was modified to use both the standard Businger-Dyer profile functions of T and Q and a new form of the functions suggested by C. Friehe that were derived from UCI vertical array sensors during the RED experiment. Calculated results of the propagation model using meteorological inputs from either the UCI array or the NPS buoy in combination with either the Friehe or Businger-Dyer Phi function forms yield essentially the same standard deviation and mean of the differences between the observed and modeled propagation loss. This is likely attributable to small spatial and temporal variations in the meteorological conditions along the propagation path. Although the standard deviation and mean errors are important statistics, one needs to recognize that the propagation model, in the global sense, correctly accounts for a large portion of the signal enhancement due to evaporation ducting. I.e., if one discounts the effects of evaporation ducting and considers only propagation in a standard atmosphere (commonly assumed in system design work) the mean differences between observed and calculated propagation loss rises to 10-15 dB at S Band, and 20-30 dB at both X- and Ku Band. For example, Figure 1 illustrates the comparison of observed and modeled propagation loss for the high-sited and low-sited X-band links during RED. The reference lines labeled "free space" correspond to the propagation loss expected if the link paths were in free space, that is, a vacuum with no obstructions between the transmitters and receiver. The reference lines labeled "troposcatter" correspond to the propagation loss expected for the antennas sited as they were on the earth's surface with atmospheric conditions of a well mixed troposphere corresponding to a monotonic refractive gradient of 118 M/km, or a so-called standard atmosphere. Clearly, evaporation duct effects on microwave propagation links low to the sea surface are significant and these effects can be reasonably modeled. However, additional work is needed to confirm the new profile functions and to understand their effects on microwave propagation over the sea.

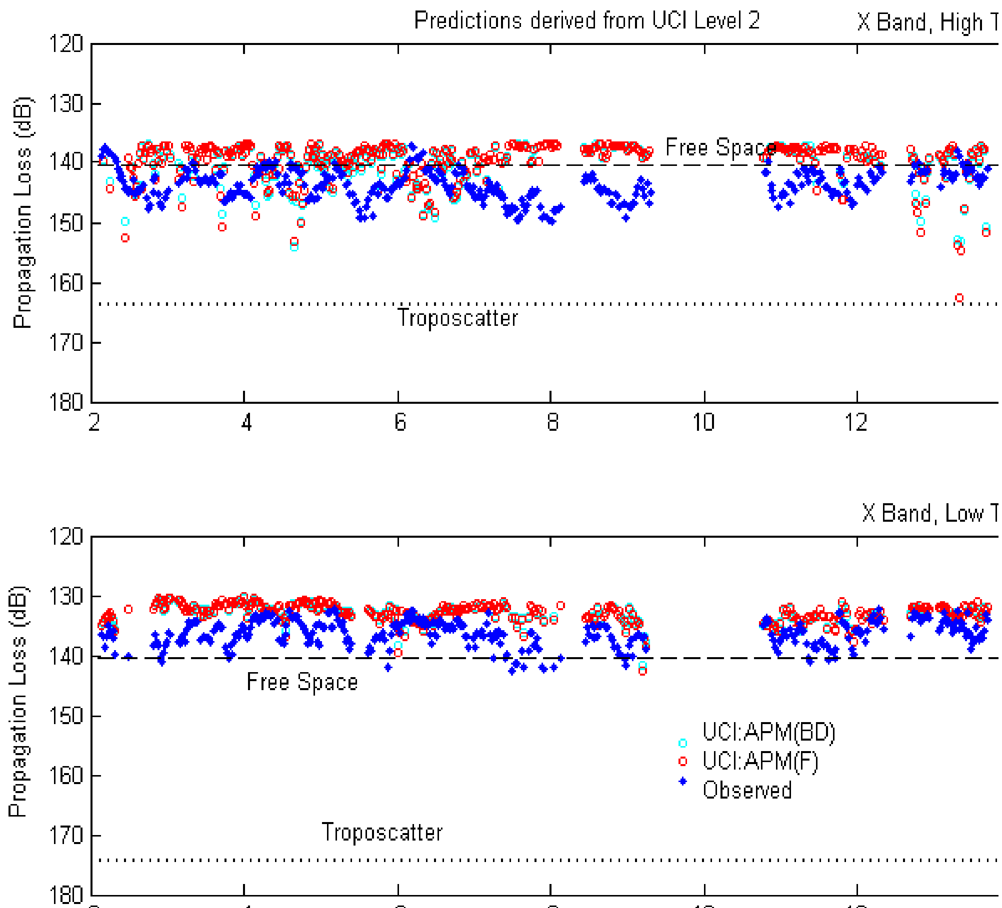

Figure 1. A comparison of observed to modeled propagation loss for the RED X-band microwave links. The mean and standard deviation of the difference between the observed and modeled propagation loss is 0.8- and 3.4 dB for the high sited transmitter and 3.4- and 2.8 dB for the low sited transmitter. The signal levels are near free-space for the high transmitter and exceed free-space levels for the low transmitter.

IMPACT/APPLICATIONS

The goal of this work is to produce an operational hybrid radio propagation model for incorporation into U.S. Navy assessment systems. Current plans call for APM to be the single model for all radio propagation applications. As APM is developed it will be properly documented for delivery to OAML, from which it will be available for incorporation into Navy assessment systems. The extension of APM to model sea and land clutter will improve operational assessments and also provides modeling support for a related project pursuing the concept of extracting refractivity profile information from radar clutter returns.

TRANSITIONS

APM Version 1.3.1 was transitioned into the Tactical EM/EO Propagation Models Project (PE 0603207N) under PMW 155 which has produced the Advanced Refractive Effects Prediction System (AREPS). Academia and other U.S. government are also utilizing APM/AREPS. A recent example of the latter is the Yuma Airways Sector of the Federal Aviation Administration using AREPS to provide insight to a solution for the FAA's problem of losing radar aircraft tracks in the Western Pacific region.

RELATED PROJECTS

This project is closely related to the synoptic and mesoscale numerical analysis and prediction projects pursued by NRL Monterey and the Coastal Variability Analysis, Measurement, and Prediction (COVAMP) project which pursue providing the refractivity inputs for APM. This project is also related to the Remote Refractivity Sensing project under ONR 321SI in providing fast-running, high-fidelity forward propagation modeling used in the RRS inference techniques. The transition target for this project is the Tactical EM/EO Propagation Models task under PMW 155 and the Oceanographic and Atmospheric Master Library. Tri service coordination is conducted under the Technology Area Review and Assessment.

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